Microgrid Energy Management System in a Public Building

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***Abstract*— Penetration of renewable energy sources, as distributed sources, and market liberalization have introduced a new concept in the power system. This globally new concept is to some extent based on the stochastic production of renewable energy sources which creates imbalance between production and consumption. One possible solution for that imbalance is a generally accepted concept of microgrids. Microgrids as an integral part of the power system, combine distributed energy sources, energy storage and load. However, in order to develop and deploy microgrids it is necessary to ensure active management of distributed sources and distribution networks. The aim of this paper is to present implementation of a microgrid in a public building by describing the concept of microgrids and offering a variety of models. Apart from indicating the possibilities and advantages of microgrids, the models identify main technical drawbacks and limitations.**

Keywords—distributed production; microgrids; photovoltaic power plants; wind turbine

I. INTRODUCTION

Liberalization of the electricity market has caused significant changes in the power system. Previous practice, with a centralized generation or vertical organisation of power flow has been slowly abandoned. New trends in the power system development are focused on distributed generation (DG) of electricity. Distributed generation, based on renewable energy sources, is globally accepted and most European countries support and develop such systems. However, regardless of the location and the power flow, the main task of the power system is to maintain the balance between production and consumption [1].

Most distributed generation is connected to medium or low-voltage networks (Fig.1). The stochastic nature of renewable energy sources and their rapid implementation creates problems in those networks. The problems include two-way flow of power, overhead power lines, ageing infrastructure, and power quality. Generally speaking, the existing passive distribution grids will become active. [2] The main objective of such an active distribution grid is to increase efficiency by reducing power flow and losses in grid fields. Active networks, in addition to efficiency, enable the use of

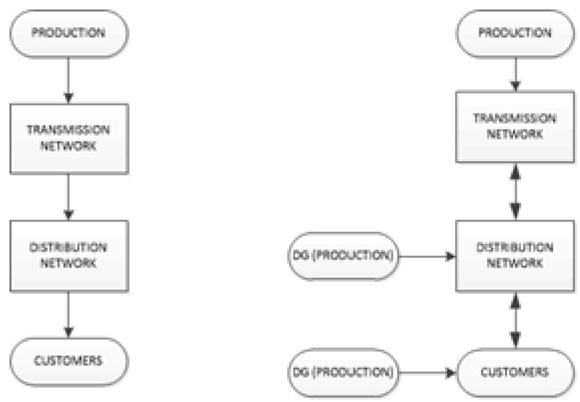

Fig 1. Passive and active power system [3]

distributed generation, energy storage, and application of new technologies. They also should take any surplus energy generated by individual consumers Thus, great emphasis is placed on high-quality electricity. The realization of such a distribution network requires the use of ITC systems, providing implementation of microgrids as a new concept.

1.1. MICROGRIDS

The use of renewable energy through distributed generation, energy storage and combination thereof as a hybrid system has led to a new concept called microgrids [4]. Microgrids, based on renewable energy sources, belong to a smart grid concept. The interdisciplinary concept of smart grids is defined by a set of technical solutions that are crucial in enabling technology for the development of renewable energy sources. The vision of smart grids is evident through a digital optimization of power distribution, utilization of alternative energy sources and increased network security [5].

Microgrid, as the building block of a smart grid, is based on a network control possibility. Control at the distribution level refers to interfacing of distributed generation including micro generators, fuel cells, wind turbines and photovoltaic systems along with energy storage devices. [6]

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The most common energy storage devices are batteries, flywheels, supercapacitors and superconducting magnetic energy storage tanks. [7]

The microgrid architecture (Fig.2) includes a few radial feeders, which can be part of the distribution system or the electrical system of a building. Regardless of which system it is, such a network is connected with the grid through a common connection point (PCC).

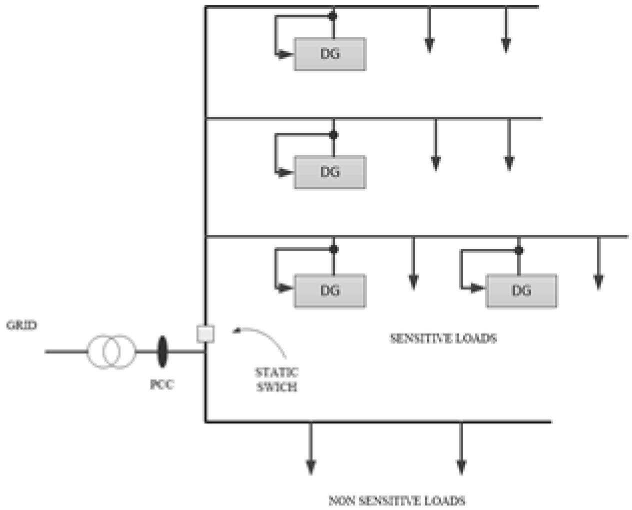

Fig 1. Passive and active power system [3]

Microgrid feeders are classified in relation to sensitivity of consumers. Feeders with sensitive consumption require local generation and they can be disconnected from the main grid via a switch or operate in island mode. It is important to ensure that local generation meets the needs of sensitive consumers. Fig. 2 presents four micro sources in nodes which control the operation of the system independently. However, if a problem occurs on local generation nodes, the switch will isolate that part of the network, whereas the feeder with the insensitive load remains in operation. In normal conditions, the energy from distributed sources can be redirected to feeders of the insensitive consumers. [8]

II. MICROGRID MODELS IN THE LABORATORY FOR RENEWABLE ENERGY SOURCES (RES)

Laboratory for Renewable Energy Sources at the Faculty of Electrical Engineering, Computer Science and Information Technology Osijek (FERIT) was established in 2014 and consists of two units, inside and outside the building. The outside unit of the Laboratory is located on the roof where measuring probes, five different photovoltaic modules and a photovoltaic power plant with the installed power of 10kWp are situated. The power plant is equipped with an inverter and protective devices and connected to the building. The generated energy reduces the total consumption of the building. In the inside unit, measuring equipment, instruments and The microgrid models provide a better insight into the role energy storage devices are used in research of microgrids. A variety of microgrid models have been developed in order to design a suitable one. The main idea is to create a model to cover the energy consumption of the building, store the surplus energy and used it when needed.

The proposed microgrid models (Fig.3.) use the existing infrastructure together with microgrid elements such as energy storage devices, wind turbines, smart meters etc. These elements are not part of the Faculty's infrastructure.

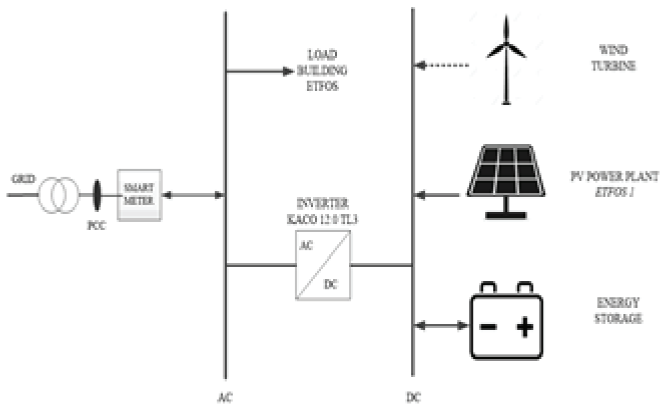

Fig.3..Proposed microgrid model

of individual elements of microgrids and depict specific advantages and disadvantages. The emphasis of the model is placed on the building load management in order to save energy and reduce peak load.

Test measurements were performed in the building from 7 June to 14 June 2014 and involved measurement of the total electricity consumption of the building and generation of the photovoltaic power plant. The consumption of the entire building was measured at the main distributor. Generation of the photovoltaic power plant was measured in the Laboratory for Renewable Energy Sources in the control cabinet on AC side. For those measurements, power network analysers were used together with the appropriate mathematical software. The obtained results presented periods of 10 minutes. The data on wind speeds for 2015 were obtained from the Meteorological and Hydrological Service. The measurements were performed at the measurement site Klisa, at a height of 10 m above the ground.

2.1. CASE I: MODEL OF THE PRESENT SITUATION (PV 10 kWp)

The model presents the existing photovoltaic power plant ETFOS 1 with 10 kWp capacity. The power plant is connected to the building and, together with the electricity grid, generates energy for the building. Fig. 4 shows the ratio of energy generated by the photovoltaic power plant and the total consumption of the faculty building. The power of the photovoltaic power plant does not meet minimum energy requirements of 16.5 kW and it only reduces the peak load and achieves energy savings of 7.82%.

Current - voltage (I-V) characteristic is a measure of photovoltaic module quality. It consists of three output parameters: short-circuit current I_{SC}, the open circuit voltage V_{OC}, and the point of maximum power (P_{MPP}). Output power

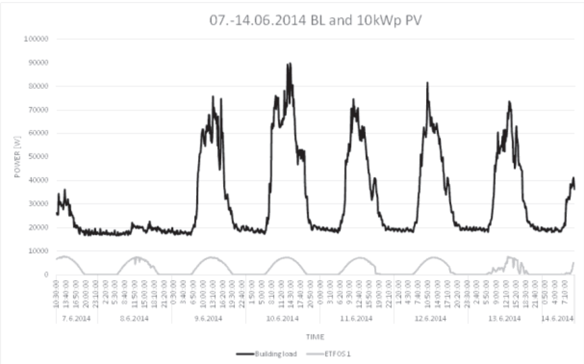

Fig .4. The ratio of energy generation and consumption

(P_{MPP}) of the photovoltaic cell is a point on the I-V curve which is obtained by multiplying the maximum current and maximum voltage I_{MPP} V_{MPP} or [9]:

$$P_{MPP} = V_{MPP} \cdot I_{MPP} \tag{1.1.}$$

Open circuit voltage V_{OC} is determined by the photocurrent, diode current, and the temperature of the photovoltaic cell. Diode current entirely depends on the material of the cell and the design of its structure. In addition to the design of the cell structure and the material, photocurrent depends on the intensity of solar radiation. Thus, the current of a photovoltaic cell, without taking into account the serial and parallel resistance, is defined as:

$$I = I_f - I_d - I_p = I_f - I_0 \left[e^{\frac{e(V+IR_s}{mkT}} - 1 \right] \tag{1.2.}$$

where I_f is photocurrent, I_d – diode current, m- cell parameter, *k* - Boltzmann's constant, and T is the absolute temperature.
The measurements have been constantly performed in the RES Laboratory and the obtained data are being stored in a database. The measured data are: current, voltage and the temperature of photovoltaic modules, solar energy and power quality. Three-phase network analysers, FLUKE 1745 and FLUKE 1760, have been used to measure power quality in accordance with HRN EN 50160: 2012. Voltage characteristics of the electricity supplied from the public distribution system are measured in accordance with EN 50160: 2010.

2.2. CASE II: MODEL OF A 40 KWP PHOTOVOLTAIC POWER PLANT

In the second case the existing 10 kWp power plant has been upgraded by 30 kWp and the measured 10-minute data from the ETFOS 1 photovoltaic power plant have been increased four times [10]. The reason for selecting a 40kWp power plant is a limited roof area. The analysis of the obtained results (Fig.5) shows that, except during weekends, power generation is not sufficient to meet daily needs of the building

As was to be expected, during weekends power consumption reduces significantly due to less activity in the building. A 40 kWp PV power plant, besides meeting daily needs of the building, generates more energy which could be stored. The total amount of energy that could be stored in the energy storage devices is 47.56 kWh, or on Saturday up to 3.54 kWh and 44.02 kWh on Sunday respectively

The main flaw of this model is the fact that the total energy output of photovoltaic power plant must meet 24- hour energy requirements. The obtained amount of energy has to be increased by the energy storage device use factor and the equipment aging also has to be taken into consideration. Energy requirements, stochastic generation from photovoltaic power plants and limited generation depending on daylight, require construction of huge power plants capable of generating enough energy to meet energy demand at night well. However, to build such power plants in urban areas is almost impossible.

2.3. CASE III: MODEL OF A 40 KWP PHOTOVOLTAIC POWER PLANT AND TWO WIND TURBINES (5kW AND 20kW)

The model envisages 24-hour operation time. That way the required area of a PV power plant could be reduced, whereas the operation time of the source would be extended. In that case, a wind turbine would be used as a secondary source which, due to its mode of operation and size, meets the above requirements. Wind speed hourly data for calculation of wind turbine power, were obtained from the Meteorological and Hydrological Service, Department of Meteorological Research.

Hourly data for 2015 were measured at a height of 10 meters above the ground at the measuring station Klisa. The obtained hourly wind speed data refer to average hourly wind speed for each month. In that way, monthly average mean hourly velocity is shown as one day. However, the anemometer is at a significantly lower height than the faculty building.

Therefore, wind speed was determined by analytical calculation at a height of 30 m above the ground, taking into account the height of the Faculty building with the friction coefficient value for particular types of terrain being 0.4 [11]. After analytical data processing the obtained wind speed values were relatively small, i.e. according to Beaufort wind force scale [12] they belong to the second category of wind speed.

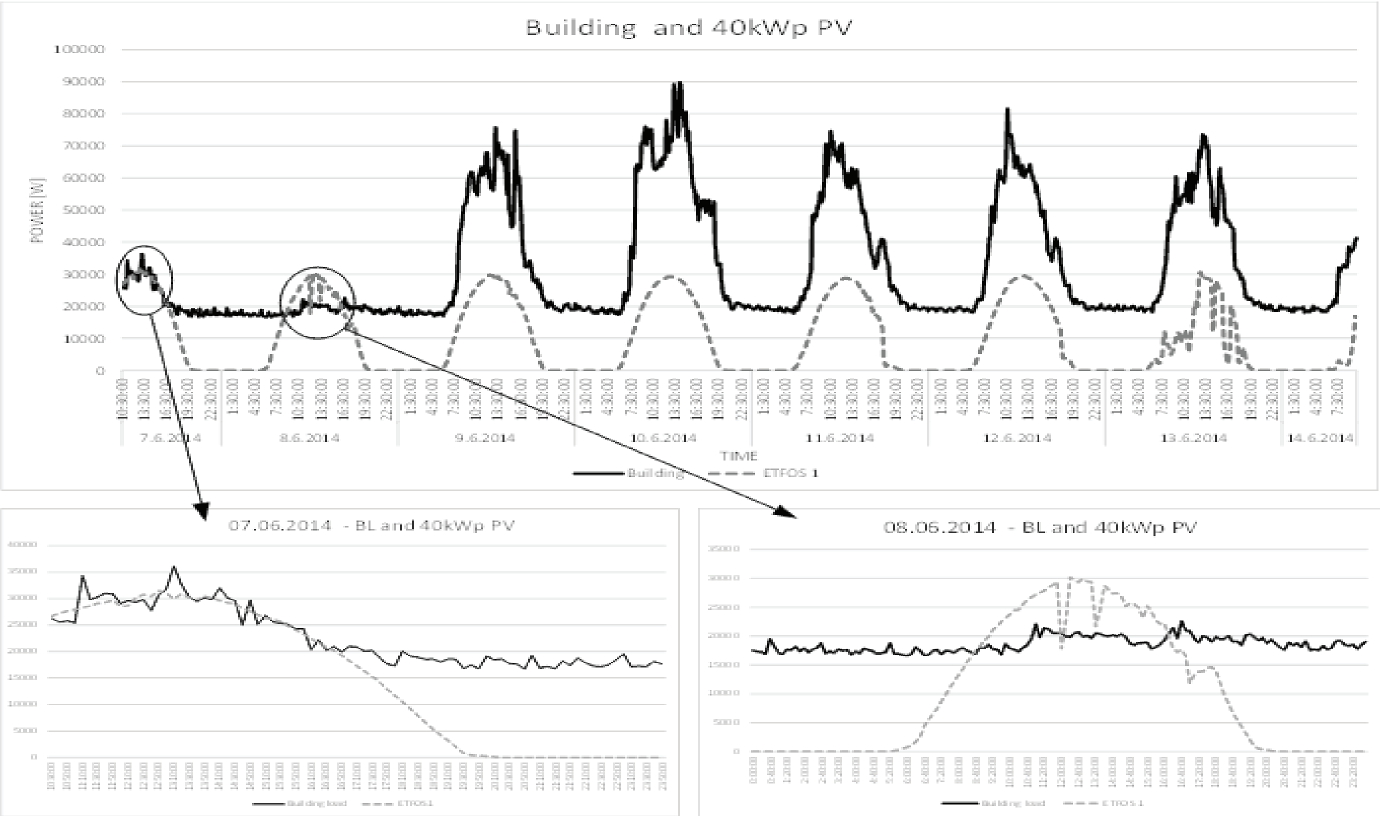

Fig .5. The ratio of energy produced a 40 kWp photovoltaic power plant and total consumption of the building

Using MATLAB software the obtained average hourly values were approximated at 10 minute values. Based on those values of wind speed, three wind turbines were considered: Fortis Wind Energy Montana, Bergey 1-D and Honeywell model StarGate [13, 14]. Comparison and analysis of the collected data for the simulation of wind turbines in MATLAB software confirmed that Honeywell StarGate curve (Fig. 6.) [15], was the most suitable.

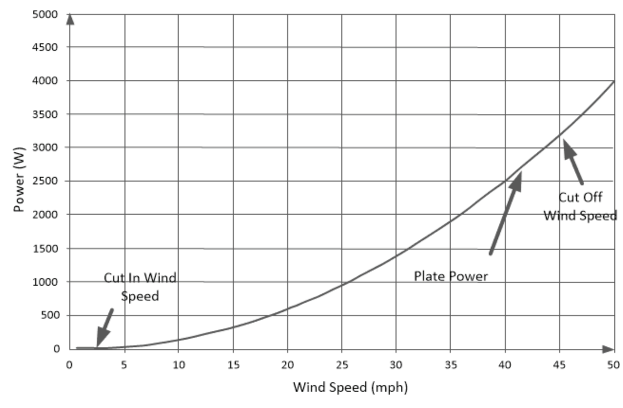

Fig 6. Wind turbine power curve - Honeywell StarGate [13]

The results obtained by simulation are presented in Fig. 7. The graphs show a 10-minute power output of 5 kW and 20 kW wind turbines. Their output power was compared with the photovoltaic power generation and the total consumption of the building.

One of the major constraints for that model of wind turbines is the fact that the region is not suitable for wind turbines due to insufficient wind. Since wind power, including the power of wind turbines, depends on the third power of the wind speed, this wind turbine model as a secondary power supply requires wind turbines to be installed at a height of at least 50 m above the ground.

2.4. CASE IV: MODEL OF A 40 kWp PHOTOVOLTAIC POWER PLANT AND 20 kW AGGREGATE

The faculty building, with average night load of 17 kW and a daily peak load of about 90 kW, requires strong power sources. Such a large load, providing that electrical grid is not used extensively and the surplus energy is not submitted to the grid, limits the choice of the power source to a biodiesel aggregate. That renewable energy source with a minimum power output not less than 20 kW could meet nightly load demand and significantly help reducing the daily load. A biodiesel aggregate with more than 20 kW power output and a

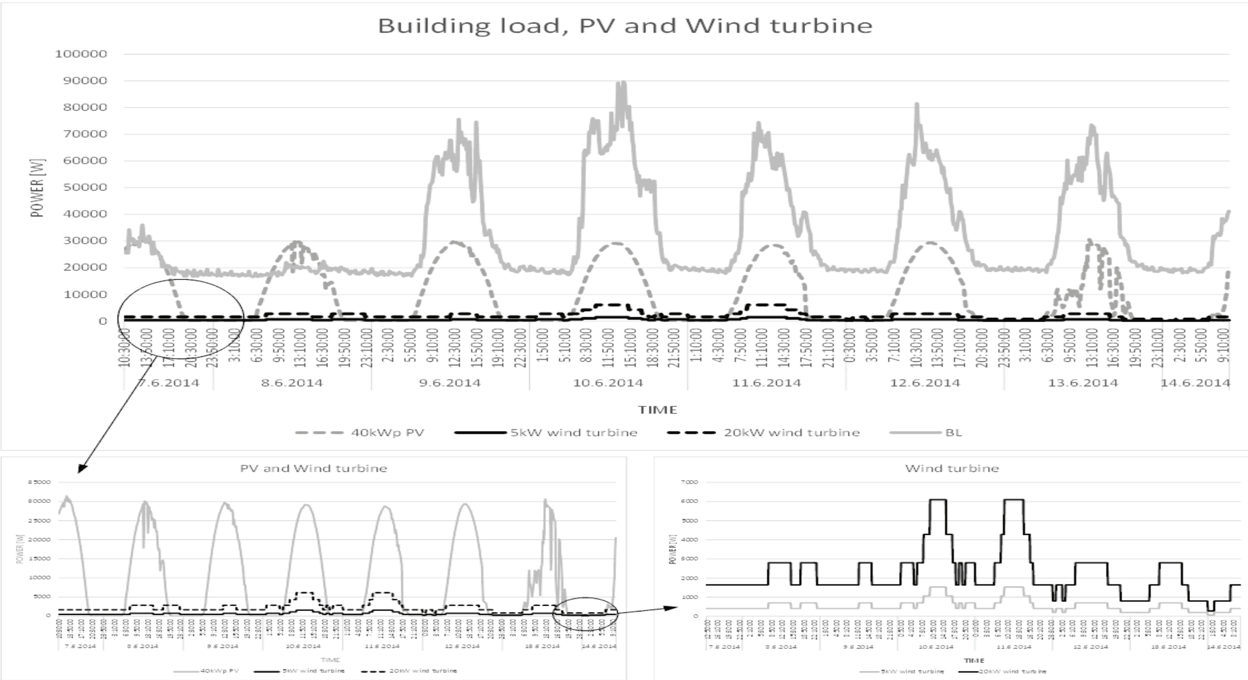

Fig 7. Total load of the building and the PV power plant and wind turbine generation

40 kWp PV power plant would require installation of energy storage devices which would certainly contribute to supply independence and increase the efficiency of microgrids. Fig 8. presents a model that uses a 40 kWp photovoltaic power plant and 20 kW biodiesel aggregate. The model meets the Faculty's energy demand to some extent. The analysis of total consumption of the building and power generated by both PV power plant and a biodiesel aggregate confirmed the power energy deficit of 307.51 kWh or 5.78 % respectively.

The main requirement of this model is an energy storage device for surplus energy which would be used if the PV power plant and the aggregate failed to meet the load demand.

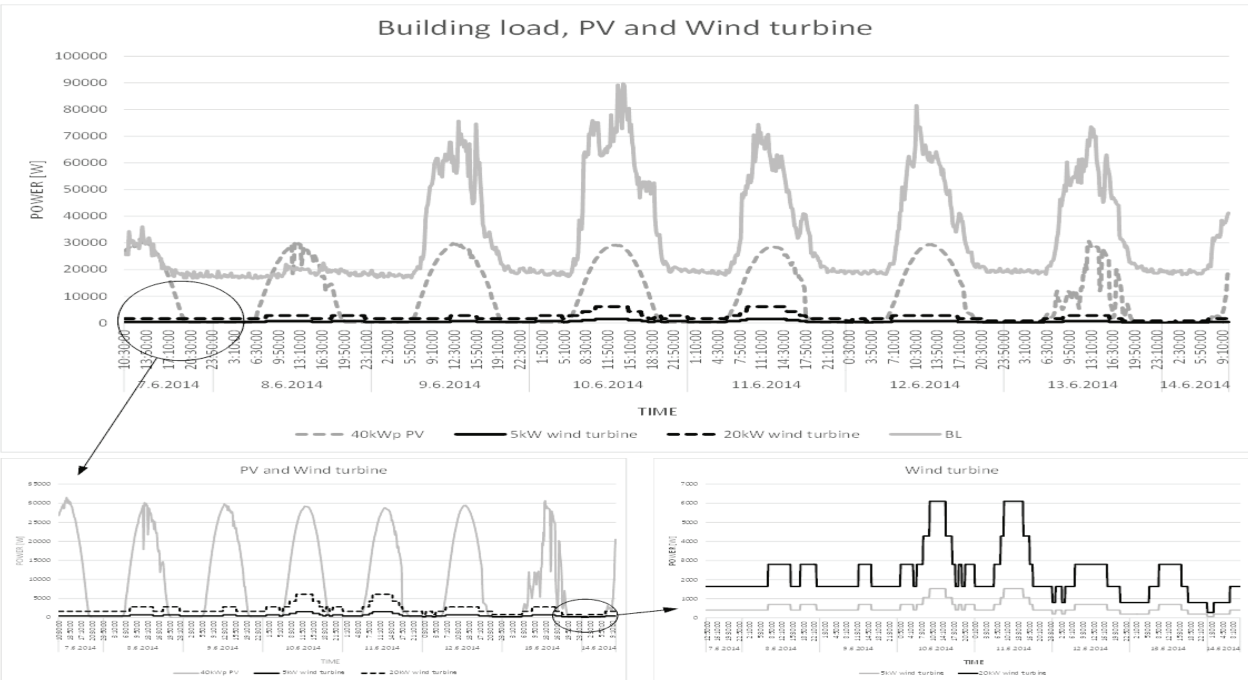

Fig. 8. Total electricity consumption by the building and generation of the PV power plant and wind turbine

III. CONCLUSION

Microgrids are one of the features of a future power system. Their radical departure from a previously centralized system creates new challenges for energy management system. The presented models definitely give reason to believe that microgrids could to meet the growing demand for electricity. Our future research within international (EU) projects will aim at developing an ideal microgid model for the Faculty building taking into account its geographic location. The intention is to reduce electricity cost and increase the proportion of RES in power supply. In addition, in cooperation with our research partners from Hungary and Serbia the aim is to make the concept of microgrids widely acceptable.

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